



**High performance vertical contour grinding/milling
for Wankel engine production.**

**Century-Detroit
Babcock & Wilcox**

Century-Detroit high-performance grinding machines.

Century-Detroit is a unit of the Automated Machine Division/Babcock & Wilcox—an organization that's been designing and building production machines for engines for well over 50 years. We do this by working with our customers to develop new and better solutions to their manufacturing problems.

Century-Detroit is probably best known to you as a pioneer in the development and application of hydrostatic bearings.

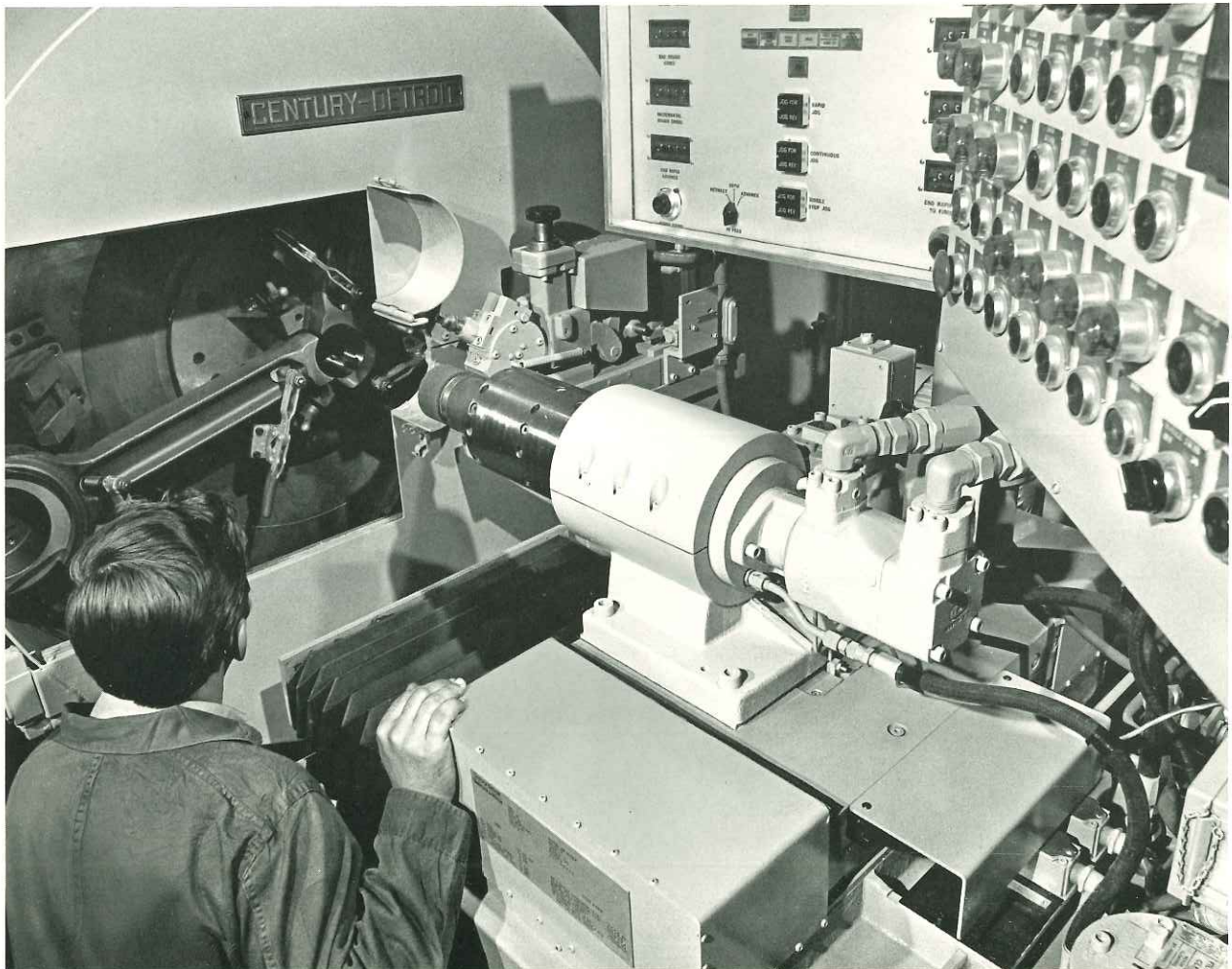
In hydrostatic bearings, bearing surfaces are separated by a film of oil under high pressure. Movement of machine members is virtually frictionless. Stick-slip, which may cause geometric inaccuracies, chatter and vibration, is virtually non-existent. Wear of sliding or rotating components is

practically eliminated. This increases machine life, insures long-term accuracy of finish operations in machine tools and helps dampen vibrations.

In the 1950's, we started to build very large equipment for the aerospace industry — rotary tables more than 30 feet in diameter, for example — that employed hydrostatic bearings.

It wasn't too long before we were applying hydrostatic bearings to machine tools for both metal cutting and grinding applications.

The most important benefit of hydrostatic bearings for grinding machines is that high dynamic stiffness is attained. Variations in loads and forces that could cause deflection of a slide or spindle with mechanical bearings are automatically com-



Universal ID grinder, designed and built by Century-Detroit, is a high-performance machine, capable of double the production of conventional ID grinders. Depths of ground holes can be held to 0.0001 inch; diameters can be held to 0.00005 inch over full length, while producing surface finishes of 10 micro-inches or less. The machine shown here has been tooled up to grind the ID at one end of a connecting rod for a diesel engine used to power locomotives. It may be required to remove up to ½ inch of stock on the ID. The machine's high horsepower permits fast stock removal.

pensated for. And the ability of the machine to remain stiff under heavy loads and forces makes it possible to use exceptionally high grinding horsepowers and heavy feeds.

Our first hydrostatic grinder was a big one, designed to contour-grind the powder chambers of 175 millimeter gun tubes. This machine grinds the ID's of holes that are 80 inches deep. It maintains a 16 micro-inch surface finish over this entire depth. Equipped with a compact, yet powerful hydraulic motor in the spindle extension, this machine reduced powder chamber grinding time by 50 hours.

After we built several of these gun tube powder chamber grinders, the aerospace industry asked us to design and build rather similar grinders for landing gear components. These machines are being used to grind landing gear for large jumbo jets.

Like the gun tube machines, these machines employ hydrostatic bearings in longitudinal slides, workheads and spindles. They're equipped with an electrohydraulic stepper motor control system which has since become standard on all Century-Detroit grinders.

The off-the-road equipment industry was another customer. And, like the ordnance and aero-

space industries, it had difficult grinding problems. Many components are large and cumbersome and do not lend themselves to being rotated. Our solution to the problem was development of a grinder in which the workpiece is stationary and the grinding wheel orbits around the workpiece.

Century's hydrostatic orbital grinder is a universal machine, capable of handling a variety of workpiece sizes and configurations for both external and internal grinding.

We've also developed medium-sized universal internal grinding machines. Thanks to their hydrostatic bearings, these machines can utilize three times the horsepower of conventional internal grinding machines of the same size and they're at least twice as productive.

Today's Century-Detroit grinders are called "high-performance grinders." They're fast, accurate, and automatic. They're true production machines, designed to deliver optimum performance under high-production conditions, as proved in scores of demanding abrasive machining applications. We're ready to apply the same concepts and production-proven hardware to new grinding and milling problems as in rotary engine production.

Wankel production... machining the epitrochoid.

A typical vertical contour grinder is illustrated in Figure 1. The part — an epitrochoid combustion chamber — is fixtured on a rotary table, which is mounted on a longitudinal slide. The grinding spindle is positioned in a fixed overarm.

Rotary motion of the table and reciprocating motion of the slide, synchronized by a gear train, generate the desired shape in the workpiece.

This type of contour grinding machine is acceptable if your production requirements are low.

But when you're grinding epitrochoid combustion chambers on a production basis, you run into problems.

The epitrochoid combustion chamber is a complex geometric form, and requires what amounts to ID and OD grinding in the same part. The attack angle (Figure 2—theoretical point of contact between grinding wheel and part) of the grinding wheel varies continuously throughout each pass around the wall of the chamber, which means you'll be unable to grind at constant surface speed. Unless you vary the speed of the part to compensate for its changing radii, you can experience poor surface finish. Present-day vertical contour grind-

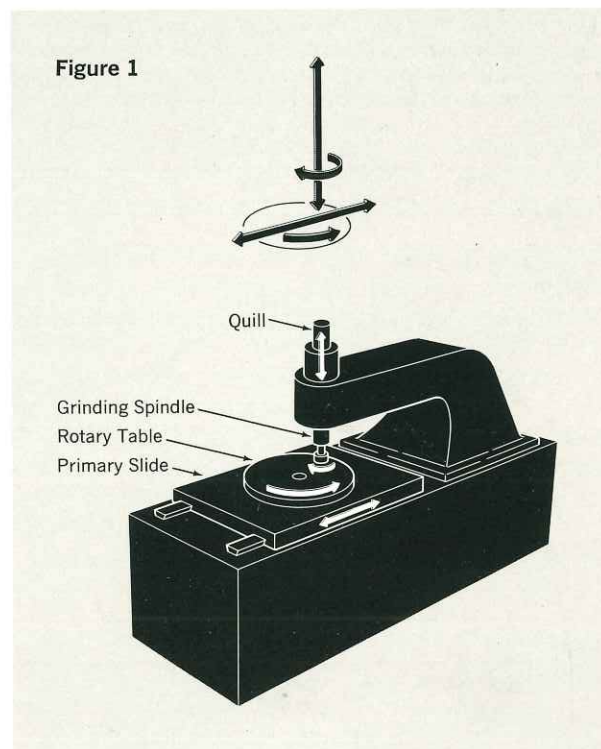


Figure 1
Standard vertical contour grinder. A combination of work table rotation and slide reciprocation, synchronized by a gear train, produces the desired workpiece shape. This machine must be run at very slow speed to obtain good finish and accuracy.

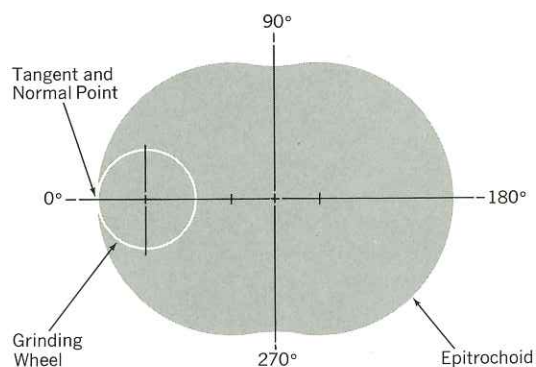
ing machines compensate for this deficiency by rotating the table at very low speed, to attempt to average out the effects of varying radii.

Even when the table is rotating at low speed, a conventional vertical contour grinder is subject to another kind of error, called "R-theta error"—Figure 3. This is caused by tooth-to-tooth error in the gear train, which causes a loss of synchronization

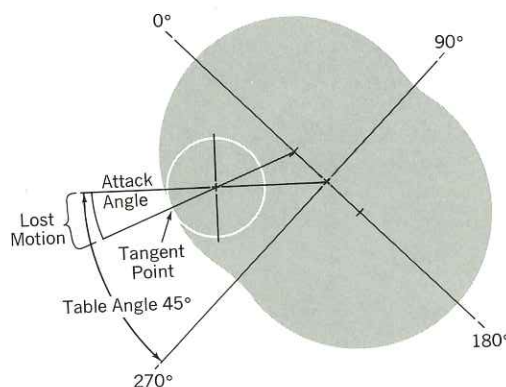
between the rotary table and reciprocating slide. The result is an abnormal radius in one or more quadrants of the part. This slow rotation isn't practical in a production grinder, where an output of 20 to 25 housings per hour is mandatory.

These are only a few of the problems associated with machining the complex Wankel epitrochoid combustion housing.

Figure 2

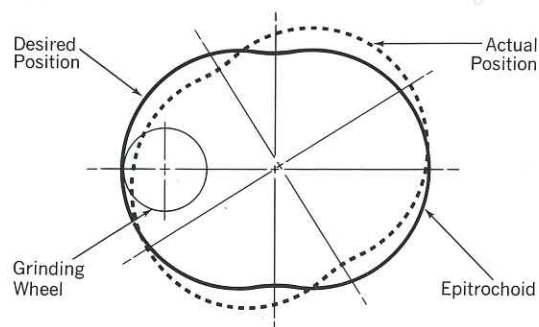


Changing attack angle of wheel is a problem when grinding this combustion chamber. At 0, 90, 180 and 270 degrees, wheel is normal to the work. At all other points, the angle of attack varies with varying radii. Most of the chamber wall requires ID grinding, but the equivalent of OD grinding is required to grind the hourglass configuration in the vicinity of 90 and 270 degrees.

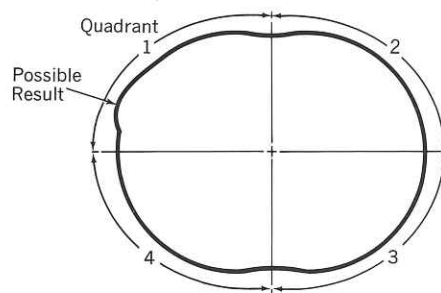


Changing radii affect the attack angle of the grinding wheel as the epitrochoid is rotated during the grinding cycle. This makes it impossible to maintain a constant material removal rate when using a conventional contour grinder. Lost motion of the grinding wheel can result in poor surface finish.

Figure 3



Geometric inaccuracy of conventional contour grinding machines is a result of "R-theta error"—caused by loss of synchronization between rotating and reciprocating elements. The loss of synchronization is a result of tooth-to-tooth error in gearing. Here the desired position of the workpiece (solid outline) is contrasted with the actual position of the workpiece (dotted outline).



Effect of "R-theta error" is shown in exaggerated form. There's an abnormal radius in one quadrant of the epitrochoid combustion chamber. "R-theta error" prevents the machining of exact duplicate quadrants in the epitrochoid combustion chamber.

Century-Detroit vertical contour grinding/milling.

The principle of our new vertical contour machine is illustrated in Figure 4. We call it a "machine" instead of a grinder because it has milling capabilities, too.

The reason we've given our new grinder milling capabilities is that it will be able to handle a broader range of materials. The combination of milling and grinding or "green" and finish grinding covers most known material combinations such as electroplating, heat treated cast iron, plasma spray, and sintered iron.

To quickly give you an idea of how our new machine differs from a conventional vertical contour grinder, Figure 4 is of a conventional grinder with one big difference—this grinder's overarm is mounted on a longitudinal slide. Movement of this slide (we call it secondary slide) compensates for positioning errors caused by the rapid reciprocating movement of the primary slide.

Of course, our new machine doesn't look like a conventional contour grinder. Figure 5 is a rendering of the prototype—Figure 6 is the exploded view.

The combustion chamber housing is fixtured on a rotary table on the primary slide. The slide, driven by the primary servodrive, rotates the heavy duty primary position cam through a heavy duty gear drive. Rotation of this high-precision cam reciprocates the primary slide through compensated cam followers on the bottom of the primary slide.

A ball spline located on the end of the primary positioning cam drive shaft, transmits power to a precision helical pinion gear. This pinion gear, in turn, drives a helical bull gear on the bottom of the rotary table—driving the table.

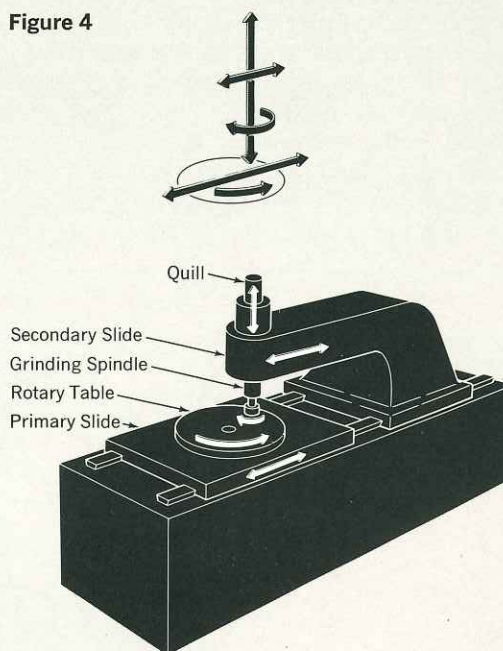
The combination of the primary positioning cam and helical gear train generates the epitrochoidal shape of the rotary engine combustion chamber. And if we were content to produce combustion chambers at low production, our machine design could stop at that point.

But if we speeded up the reciprocation and rotation to obtain high production, we'd be in trouble. Fast reversal of large machine masses would cause gear train wrapup and backlash that would result in unacceptable workpiece error.

In our new machine, minute movements of the secondary slide—a few thousandths of an inch—compensates for the positioning errors of the primary slide that occur when the machine is run at very high speeds.

We've mounted the primary slide on longitudinal hydrostatic ways on the secondary slide. The secondary slide is mounted on hydrostatic ways in the machine base.

Figure 4



Added machine movement converts a conventional contour grinder into a machine that can compensate for positioning errors caused by high-speed operation. Workpiece is mounted on rotary table on primary slide. Overarm is mounted on a secondary slide. Movement of secondary slide compensates for errors caused by the high speed reversing action of the primary slide.

Movement of the secondary slide is controlled by a master (secondary) cam, close-coupled to the part and mounted on the bottom of the rotary table. The shape of this internal (secondary) cam is an exact duplicate of the desired finished contour of the epitrochoid combustion chamber.

A tapered cam follower—actually the stylus of an electromechanical tracer valve—traces the finished shape of the master cam as the primary slide oscillates and the rotary table turns at high speed.

The centerline of the tapered cam follower is coincident with the centerline of the grinding spindle. In effect, the part can only be ground in correct orientation to the spindle. To say it another way, we've eliminated "R-theta error" by the strategic arrangement of the critical components.

To minimize the effects of changes in wheel attack angle as the epitrochoid chamber is rotated, we automatically vary the rotational speed of the table to compensate for changing part radii. This means we maintain a constant material removal

rate resulting in constantly smooth surface finish over the varying radii of the part.

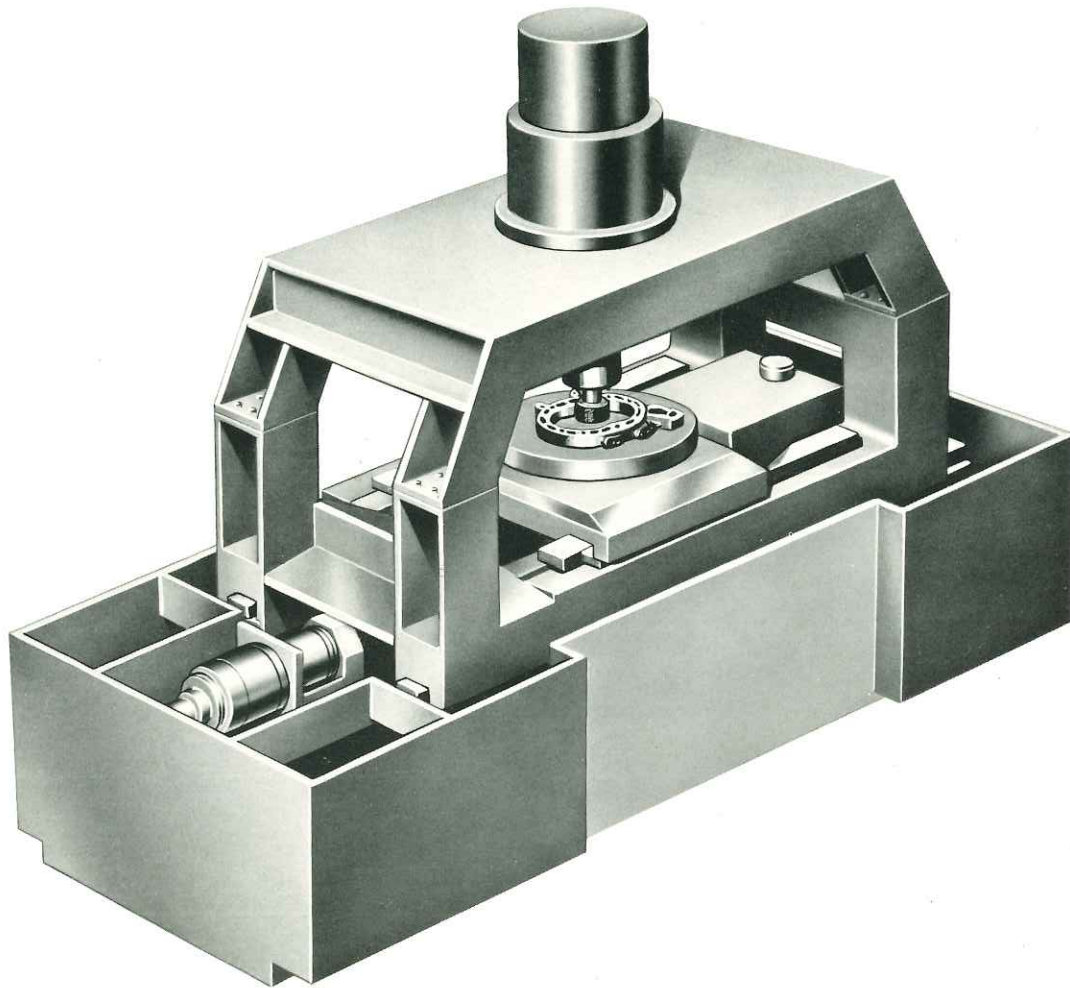
We automatically compensate for reductions in wheel diameter caused by wheel breakdown and dressing. Each time a wheel is dressed, a stepper motor retracts the tapered cam follower so the cam diameter at that point corresponds to the dressed diameter of the wheel, which maintains wheel tangency over the entire useful grinding range of the wheel. At the same time, wheel speed is automatically increased to maintain a constant material removal rate. So when we equip the machine with a grinding spindle, utilizing a direct-coupled 45 hp

drive motor, we have a vertical contour grinder that's a true high-production machine.

The machine's slides, rotary table, quill and grinding spindle are equipped with well-proven hydrostatic bearings. This will minimize wear, insure smooth operation and—most important—give the machine the dynamic stiffness it needs for consistent geometric accuracy and impart the required smooth surface finish.

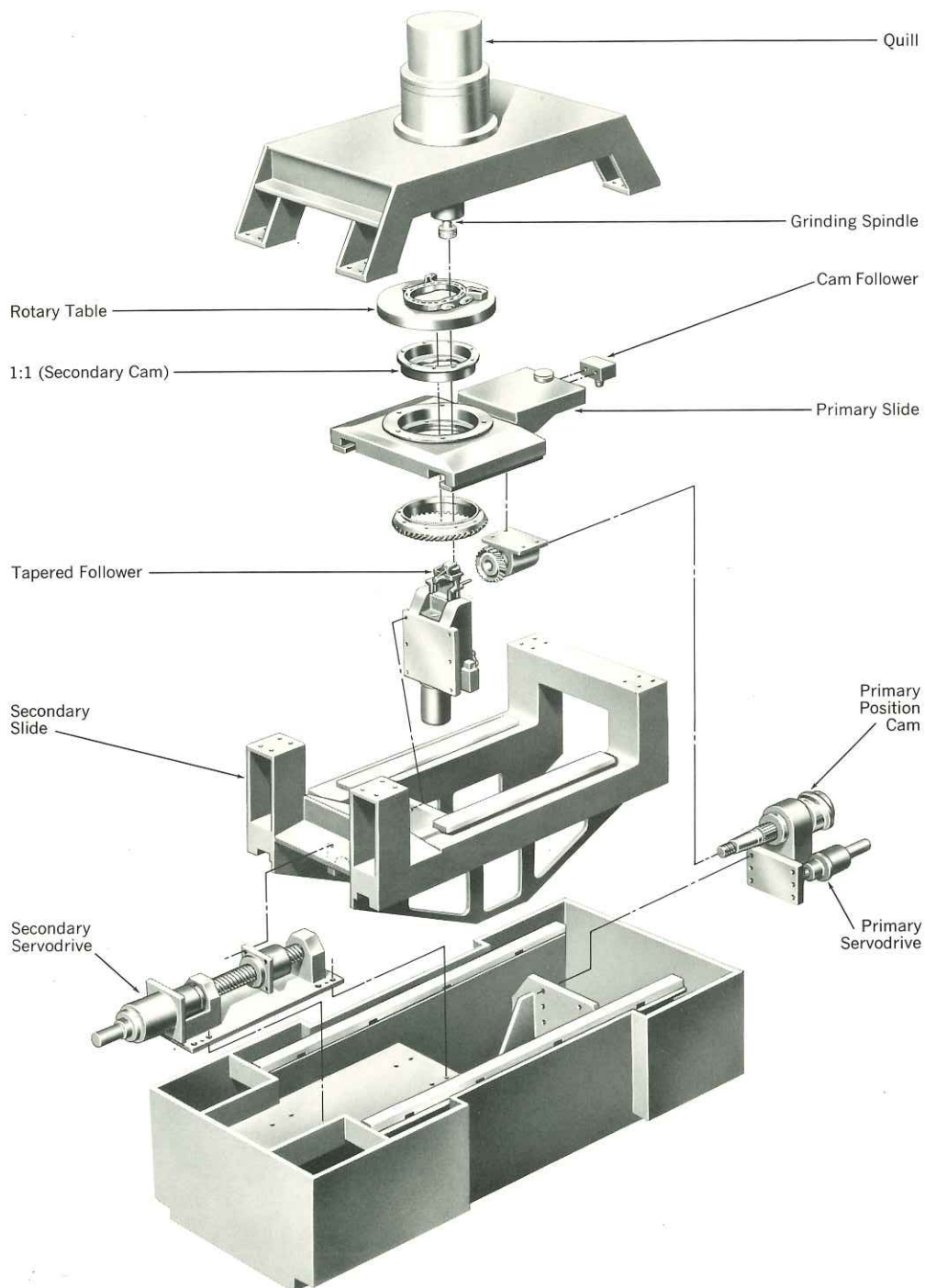
We can replace the low torque, high-speed grinding spindle with a high torque, low-speed milling head to convert the grinder into a milling machine, with the same features.

Figure 5



Century-Detroit high-performance vertical contour grinding/milling machine equipped for grinding. The 45 hp grinding spindle is mounted in a massive bridge to minimize deflection under heavy grinding loads. The bridge is part of the secondary slide assembly, which moves to compensate for positioning errors of the primary slide. The machine uses all hydrostatic bearings.

Figure 6



Exploded view of the Century-Detroit high-performance vertical contour grinding/milling machine for Wankel engine combustion chambers. Primary servodrive reciprocates primary slide and turns rotary table that holds workpiece. Secondary servodrive moves secondary slide to compensate for positioning errors of primary slide. Combination of cam and tracer control eliminates need for elaborate gear trains, makes it possible to change the ground or milled shape simply by changing cams. Permits engine design engineers to modify the geometry of the epitrochoid to compensate for distortions in the engine under operating conditions.

Design goals.

- **Production: 20 to 25 parts/hour**
- **Tolerances: ± 0.001 inch error envelope**
- **Surface finish: less than 10 micro-inches**
- **Dual grinding modes: incremental and creep (plunge) equipped with torque sensing (controlled horsepower)**
- **Automatic fixture clamping**
- **Automatic parts handling**

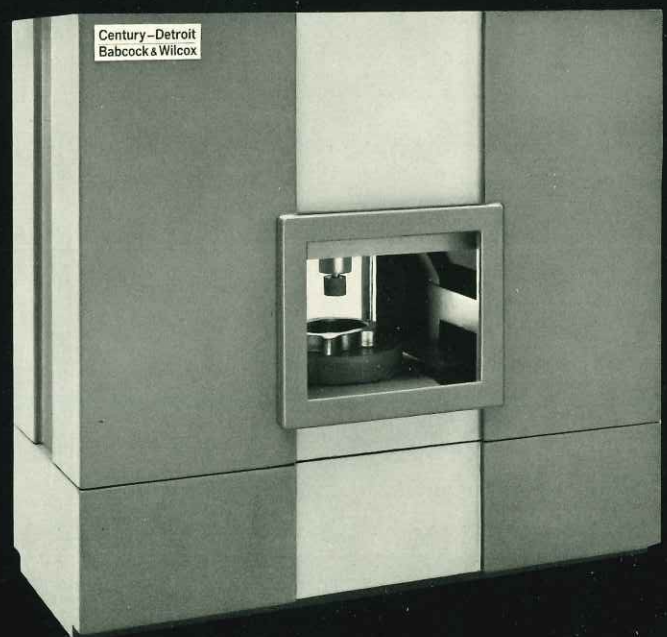
Careful consideration has been given to eliminating service and maintenance problems normally associated with special machines. There is no external piping and wiring. We have reduced the number of limit switches and other high maintenance components to a minimum.

Items that normally require periodic adjustment such as primary cam followers are hydraulically pre-loaded and self-adjusting. Both cams are readily accessible for quick change-over. Light stylus pressure on the master (secondary) cam will minimize wear and service.

Considerable attention has also been given to coolant distribution and flow to minimize swarf build-up and maximize coolant effect. Either water soluble coolants or grinding oils can be used. Hydraulic fluids will be temperature-controlled by a refrigeration unit, providing the next best thing to a completely temperature controlled grinding environment.

The electrical control system will be adaptable to manual control, program controllers, NC and DNC systems.

Century-Detroit high-performance vertical contour grinding/milling machine, with enclosure, will conform to Federal O.S.H.A. specifications. Rotary engine combustion chamber housings will be fed into the machine through the loading doors, which will be closed when the machine is operating.



For more information on the Century-Detroit high-performance vertical contour grinding/milling machine, write or call Century-Detroit, 16400 West Twelve Mile Road, Southfield, Michigan 48075. Phone: (313) 559-5225.